# A Review: Performance Study of Electrochemical Machining on Metal Matrix Composite

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## Abstract

*The review work is carried out as Aluminum matrix composites (AMCs) have become the most promising materials in many industrial applications, including electronics, bio- medicine, optics, bio-technolgy, home appliances, fuel injection system components, ordnance components mechanical machine parts such as turbine blades, engine casings, bearing cages, gears, dies, molds, all other major parts in automobile and aerospace industries. AMCs are having high modules, low ductility, high thermal conductivity, low thermal expansion,high strength-to-weight ratio, high toughness, high-impact strength, high wear resistance, low sensitivity to surface flaws, and high surface durability. Stir casting method is very popular in AMC's fabrication due to its unique advantages. The hard particles present in the matrix, poor machining properties of AMC and drilling of AMCs are challenging tasks for the manufacturing engineers. Several micro-manufacturing methods have been developed to solve these problems. Among the various micromachining, electro chemical micromachining (EMM) seems to be a potential one, because it gives good surface finish, no-tool wear, no thermal damage to the work-piece, higher machining rate, better precision, control and capability to machine a wide range of materials and complex shapes can be machined for extremely hard materials. Micromachining technology plays a significant role in the miniaturization of parts and components find applications in aerospace, biomedical and electronic industries. Considering the importance of EMM, an in-depth study is required for a better understanding of the EMM processes on to its application in micro-machining domain.*

**Keywords: -** AMCs, Industrial applications, complex shapes, EMM..,

## 1. INTRODUCTION

In many developed countries and several developing countries there exists continued interest in MMCs. Researchers tried numerous combinations of matrices and reinforcements since the work on MMCs began in the 1950s. This led to developments for aerospace, but the resultant commercial applications were limited. The introduction of ceramic whiskers as reinforcement and the development of in-situ eutectics in the 1960s aided high temperature applications in aircraft engines.). The principal matrix materials for MCs are aluminum and its alloys. To a lesser extent, magnesium and titanium are also used, and for several specialized applications as copper, zinc or lead matrix may be employed. MMCs with discontinuous reinforcements are usually less expensive to produce than continuous fiber reinforced MMCs, although this benefit is normally offset by their inferior mechanical properties. Consequently, continuous fiber reinforced MMCs are generally accepted as offering the ultimate in terms of mechanical properties and commercial potential. While a variety of matrix materials has been used for making MMCs, the major emphasis has been on the development of lighter MMCs using aluminum and titanium alloys, due to the significant potential of improvement in the thrust-to-weight ratio for the aerospace and automotive engines. Automotive engineering is currently a major user, particularly in hot reciprocating applications such as pistons for both diesel and petrol engines where hot-strength and resistance-to-thermal fatigue are markedly improved by using Aluminum matrix composites (AMCs). Other engine applications are anticipated, owing to the intense pressures upon the motor industry for better fuel economy, lower exhaust emissions and improved engine performance. These pressures are expected to intensify further as legislative, environmental and consumer demands increase. AMCs are now being used in the aerospace industry, which represents a major breakthrough in the growing acceptance of these composite materials in a market with exceptionally high levels of technical requirements. AMCs are also recognized as having an important role to play in high speed machinery applications where increased operating speeds of more than 50 % have been achieved. Furthermore, their combination of lightness, fatigue resistance, and stiffness make them ideal for many sporting applications, such as road and mountain bicycles. Applications in the defense sector are also varied and make use of some of the unique properties offered by AMCs. Other applications for AMCs will utilize their thermal and electrical properties, especially in dimensionally-stable platforms and electronic packaging. In general, the major advantages of AMCs compared to unreinforced materials, such as steel and other common metals, are as follows:

- Increased specific strengths
- Increased specific stiffness
- Increased elevated temperature strength
- Improved wear resistance
- Lower density;
- Improved damping capabilities;
- Tailorable thermal expansion coefficients;
- Good corrosion resistance.

### A. *Types of AMCs*

AMCs can be classified into four types depending on the type of reinforcement

- Particle-reinforced AMCs (PAMCs)
- Whisker-or short fiber-reinforced AMCs (SFAMCs)
- Continuous fiber-reinforced AMCs (CFAMCs)
- Mono filament-reinforced AMCs (MFAMCs.

### B. *Electrochemical Micro Machining*

Material removal techniques have a pivotal role to play in component fabrications. In recent years, many high-strength alloys are extremely difficult to machine using traditional processes.

The major difference between conventional and non-conventional machining processes is that conventional processes use a sharp tool for material removal by physical means whereas non-conventional techniques remove materials by utilizing chemical, thermal, or electrical energy or a combination of these energies.. Machining high-strength alloys with conventional tools results in subsurface damage of the work-piece and in tool damage. The tool size and geometry limit the final component shape that can be machined. Another problem with these tools is that they tend to leave burrs on the machined surface.

The machining processes are non-traditional in the sense that they do not employ traditional tools for metal removal and instead they directly use other forms of energy. The problems of high complexity in shape, size and higher demand for product accuracy and surface finish can be solved through non-traditional methods. Currently, non-traditional processes possess virtually unlimited capabilities except for volumetric Material Removal Rates. As removal rate increases, the cost effectiveness of operations also increase, stimulating ever greater uses of non- traditional processes.

Electrochemical machining is a material removal process similar to electroplating. In this process, the work-piece to be machined is made as the anode and the tool is made as the cathode of an electrolytic cell with a salt solution being used as an electrolyte. On the application of a potential difference between the two electrodes and when adequate electrical energy is available between the tool and the work-piece, positive metal ions leave the work-piece. Since electrons are removed from the work-piece, oxidation reaction occurs at the anode. The electrolyte accepts these electrons resulting in a reduction reaction.

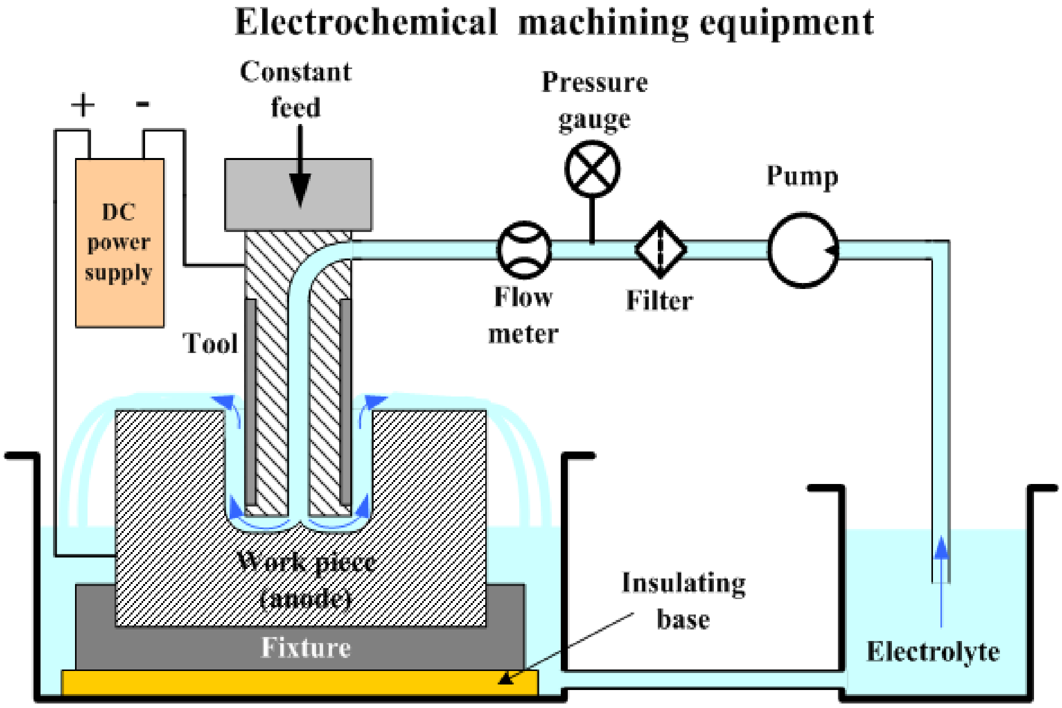


Figure 1: Electrochemical Machining

## 2. RELATED WORK

A lot of investigations have been carried out to analyze the efficient way for fabrication and efficient machining of AMCs using EMM.EMM is one of the emerging technologies for micro-fabrication. It is a method with an increasing research interest the world over; the scientific community continues to explore its potentials. After going through all the selected literature, the survey was broadly classified into four different categories; such as (i) Aluminum matrix composites; (ii) Stir casting process; (iii) EMM - experimental set-up development

### *A. Aluminium matrix composite*

**Surappa (2003)** concluded that there was an urgent need to develop simple, economical, portable and non-destructive kits to quantify undesirable defects in AMCs. Aluminum and its alloys possess excellent properties such as low density, good plasticity, ductility, and good corrosion resistance. They find extensive applications in aeronautics, astronautics and automobile and high-speed train fields. However, low hardness and poor impact resistance results in their limited application in heavy-duty environments. It has been proved that particle-reinforced aluminum matrix composites can improve the strength and hardness of aluminum and its alloys considerably. This will severely affect the safety and reliability of components fabricated from aluminum matrix composites (AMCs). **Rosso (2006)** asserted that metal matrix composites have a number of advantageous properties as compared to monolithic metals, including higher specific strength, higher specific modulus and resistance to elevated temperatures, better wear resistance and lower coefficients of thermal expansion. Also, MMCs have several superior mechanical properties over polymer matrix composites, which include greater transverse stiffness and strength, better temperature capabilities, greater compressive and shear strengths. There are also many beneficiary physical properties of MMCs, like resistance to most radiations, non-inflammability, no significant moisture absorption properties and high thermal and electrical conductivities.. During direct metal-to-metal contact, the graphite particles from composites pin surface forms a thin tribo-film between surfaces. Tearing and formation of oxide layer and graphite film is a continuous process, which results in decrement of wear rate for composite, when the operating temperatures are increased. The hard particles present in the matrix, poor machining properties of AMC and the drilling of AMCs are challenging tasks for manufacturing engineers. To meet these issues, various micro-manufacturing methods have been developed. Among the various micro-machining methods, electrochemical micro machining (EMM) appears to be potential one, because it produces good surface finish, no tool wear, no thermal damage to the workpiece, higher machining rate, better precision, control and capability to machine a wide range of materials and complex shapes can be machined for extremely hard materials **(Malapati and Bhattacharyya 2011). Prakash and Pruthviraj (2011**) mentioned that the major drawbacks of these Zn-Al based composites are reduced conductivity and poor machinability. Graphite, being a solid lubricant can improve the machinability of the composites. Furthermore, graphite possess excellent thermal and electrical conductivity thereby improving the conducting capability of Zn-Al composites. **Jayashree et al. (2013)** stated that the aluminum metal matrix composites with silicon carbide particle reinforcements are finding increased applications in aerospace, automobile, space, underwater, and transportation applications. This is mainly due to improved mechanical and tribological properties like strong, stiff, abrasion and impact resistance, and is not easily corroded. **Senthilkumar et al. (2013)** stated that the proper selection of manufacturing conditions is one of the most important aspects in the electrochemical machining process, as these conditions determine important characteristics such as Material Removal Rate and surface roughness. The material used in the study was LM25Al/10%SiCp composite. Experiments have been carried out to establish an empirical relationship between process parameters and responses in ECM process using response surface methodology. Analysis of variance (ANOVA) is employed to indicate the level of significance of the machining parameters. Electrolyte concentration had most significant influence factor on Ra rather than other parameters.

### *B. Stir casting process*

In recent years many fabrication techniques have been developed for particulate-reinforced metal matrix composites (Al/SiC MMC). These techniques are stir casting, liquid metal infiltration, squeeze casting, spray decomposition and powder metallurgy **(Nai and Gupta 2002; Balasivanandha Prabu et al; 2006).** Among the varieties of fabrication techniques available for particulates or discontinuous-reinforced metal matrix composites, stir casting is considered to be the most potential method for engineering applications in terms of its production capacity and cost efficiency. It is attractive because of its simplicity, flexibility and is the most economical for large-sized components to be **fabricated (Hashim et al., 1999, Balasivanandha Prabu et al., 2006** and **Shanmughasundaram et al., 2011). Lakhan Rathod and Purohit (2013)** concluded that, stirrer position, stirring speed and time and particle preheating temperature are the important process parameters of the stir casting process.

### *C. Electrochemical Machining (ECM)*

**Gussef** in 1929 first patented the process resembling ECM. Significant advances during the 1950s and 1960s emerged ECM as an efficient technology, in the aerospace and aircraft industries. Electrochemical machining is also another advanced machining technology which offers a better alternative or sometimes the only alternative in achieving precise 3-D complex-shaped features and components of difficult-to-machine materials. The advantages of ECM over other traditional machining processes include its applicability, disregarding the material hardness, comparable high

 

Material Removal Rate, no tool wear, and achievement of fine surface features and the production of components of complex geometry with crack-free and stress free surfaces. Therefore, ECM has been utilized in many industrial applications, including engine casings, turbine blades, gears, bearing cages, molds and dies as well as surgical implants. ECM is often termed as 'reverse electroplating', in which it removes material in place of adding it. This is totally based on Faraday's law of electrolysis**. Bhattacharyya et al., (2002**) presented a computer simulation of cut-and-try procedure for designing tool shape in the ECM of prescribed work geometry and showed that an optimum value of the feed-back factor for iterative modification of the tool shape exists. **Rajukaretal. (2007)** explained that a D.C. voltage (generally about 10 to 25 volts) was applied across the inter-electrode gap between an anode work-piece and pre-shaped cathode tool. The electrolyte (e.g. NaCl, NaNO3 aqueous solution etc.) flows at a high speed through the inter-electrode gap (about 0.1 to 0.6mm). According to Faraday's law, the anode work-piece is dissolved with the current density from 20 to 200A/cm2. The electrolyte flow takes away the dissolved material (generally metal hydroxide) and other by-products generated in the process, such as cathodic gas from the gap. Jo et al. (2008) employed micro-ECM to fabricate various 3D micro-structures such as micro-holes and micro-grooves. The final shape of the work-piece is nearly negative mirror image of the tool electrode. **Hocheng et al. (2009)** proposed a computational model to predict the erosion profile in the use of a simple flat-end electrode during the ECM process. **Dar-Yuan Chang and Shu-Yi Lin (2012)** have concluded that microdrilling is an ssential process in the electronics, aviation, and semiconductor industries. Since micro-drills have low rigidness and a high aspect-ratio, precise drilling parameters are required to prevent tool breakage from excessive thrust force or torque. They have made an attempt to machine the alumina ceramic to investigate the effects of drilling parameters on hole characteristics. **Rajarshi Mukherjee and Shankar Chakraborty (2012)** concluded that electrochemical machining (ECM) has become one of the most potential and useful non-traditional machining processes because of its capability of machining complex and intricate shapes in high-strength and heat-resistant materials. For effective utilization of the ECM process, it is often required to set its different machining parameters at their optimal levels. **Fan et al. (2012)** investigated the influences of working parameters of EMM, such as pulsed duration, applied voltage, pulse frequency,electrolyte concentration, tool feed rates, and hole depth, on the hole overcut. **Jain et al (2012)** studied the effects of process parameters such as voltage, electrolyte concentration, pulse duty cycle, and feed rate on the machined hole diameter. **Tang and Yang (2013)** observed that, given the same voltage, with an increasing cathode feed rate, the MRR was shown to increase while the surface roughness value and the side gap decreased. Under the same cathode feed rate, the MRR decreases, while the side gap and the surface roughness increase as the electrochemical machining application voltage increases.

## 3. PROBLEM FORMULATION

It is evident from the literature survey that only a few researchers have studied the performance of EMM on AMCs. Considering these requirements, an EMM set-up was developed. The literature survey also points out that not much attention has been paid to study the electrochemical micro-machining on AMCs. Most of the methods presented in the literature increase the complexity of the computational process for drilling optimum machining parameters and therefore it cannot be easily understood by engineers with limited statistical skills. So, it is required to find some methodologies to handle the existing complexity in solving single- and multi-response problem. Therefore, this research work mainly focuses on the effects of the influencing process parameters of EMM such as machining voltage, electrolyte concentration, frequency on the overcut and Material Removal Rate (MRR) of five different AMCs through Taguchi methodology and grey-relational analysis has been investigated experimentally. The fabricated AMCs cover the following application areas: piston ring, channels for micro reactors, nozzle plate for ink-jet printer head, cylinder liner, connecting rod.

## 4. PROPOSED WORK

 

The need for further studies arises with the aim of throwing more light on the possible commercialization of the technology. With due consideration to these requirements, an EMM set-up was developed and the influence of the various process parameters such as pulse on-time, voltage, current and electrolyte concentration on machining rate and overcut. EMM setup is developed for producing micro-holes in AMCs with the objective of minimizing overcut (μm) and maximizing of the Material Removal Rate (mg/min). In order to achieve this objective, the following works have been carried out in this research work. These are to:

• Manufacture the following five different AMCs through Stir casting method;

- Al 6061 - 6 % wt of Gr ; Al 6061 - 5 % wt of SiC p – 5 % of Gr;
- Al 6063 – 10 % wt of TiC; Al 6063 - 10 % wt of SiCp;
- Al 6063 - 10 % wt of SiCp – 5 % of B4C;
- Study the micrograph and hardness of AMCs;

• Develop an EMM setup;• Conduct experiments for studying the effect of process parameters;
• Optimize the process parameters through Taquchi methodology and grey-relational analysis.

## 5. CONCLUSION

Thus in this paper I conclude with the study of various reviews related ECM experiments on stainless steel and some on AMCs, but not much involvement in EMM studies. Hence,experimental studies were carried out for optimal settings of machining parameters for EMM on AMCs. The machine set-up has been developed and preliminary experiments conducted. Based on the preliminary experimental results, the ranges and levels were identified and detailed studies carried out. The effect of process parameters on EMM has been investigated experimentally for all the five AMCs using Taguchi and grey-relational analysis.

 

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